

Carnahan-Starling-DeSantis and Lee-Kesler-Plöcker interaction coefficients for several binary mixtures of ozone-safe refrigerants

James R. Sand and Steven K. Fischer

Oak Ridge National Laboratory, Post Office Box 2008, Building 3147, Mail Stop 6070, Oak Ridge, TN 37831-6070, USA

Jack A. Jones

Jet Propulsion Laboratory, California Institute of Technology, Mail Station 157-102, 4800 Oak Grove Drive, Pasadena, CA 91109 USA

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Interaction coefficients (ICs) which characterize the non-ideal behaviour of refrigerant mixtures are an important parameters for predicting or modelling the thermodynamic performance of these mixtures in air-conditioning and refrigeration cycles. Experimental data which permit calculation of these parameters for many combinations of the newer, more environmentally acceptable refrigerants are scarce. Saturated vapour pressure data for 70 known mixtures of 8 different refrigerants in 18 binary combinations were analysed to find the interaction coefficients from the best correlation between vapour pressures calculated from the Carnahan-Starling-DeSantis (CSD) and Lee-Kesler-Plöcker (LKP) refrigerant property routines and experimental data. Nine of the experimentally measured ICs were not previously given for the CSD routines in the current version of REFPROP[®] from the National Institute of Standards and Technology. Fifteen new LKP ICs are reported. Comparisons are made with both published values and those estimated using algorithms unique to each system of subroutines. Agreement between the ICs reported in this work and published or estimated values is reasonably good in most cases given the simplicity of the test apparatus and experimental procedures. Very good agreement was seen between the ICs calculated in this work and the literature values for R12/R152a, R134a/R134 and R22/F152a, but poor agreement was seen for R22/R142b. Comparisons of published to estimated ICs and reported to estimated ICs suggest that estimation techniques should be improved.

(Keywords: CFC alternatives; binary interaction coefficients; equations of state; ozone depletion)

Coefficients d'interaction de Carnahan-Starling-DeSantis et Lee-Kesler-Plöcker pour plusieurs mélanges binaires de frigorigènes sans effet sur l'ozone

Les coefficients d'interaction qui caractérisent le comportement non idéal de mélanges de frigorigènes sont importants pour la prévision et la modélisation de la performance thermodynamique de ces mélanges dans des cycles de conditionnement d'air et de refroidissement. On manque de données expérimentales permettant de calculer ces paramètres pour plusieurs combinaisons des frigorigènes nouvellement développés, qui sont moins nocifs pour la couche d'ozone. On a analysé les données sur la pression de vapeur saturée pour 70 mélanges connus de 8 frigorigènes différents, dans 18 combinaisons binaires, dans le but de trouver les coefficients d'interaction de la meilleure corrélation entre les pressions de vapeur calculées avec les programmes des propriétés développés par Carnahan-Starling-DeSantis (CSD) et Lee-Kesler-Plöcker (LKP) et les données expérimentales. Neuf des coefficients d'interaction mesurés expérimentalement n'ont pas été déjà donnés pour les programmes de CSD dans la version actuelle de REFPROP du 'National Institute of Standards and Technology' (NIST). On présente 15 nouveaux coefficients d'interaction obtenus par LKP. On établit des comparaisons avec les valeurs publiées et celles évaluées grâce à des algorithmes uniques à chaque système de sous-programmes. La corrélation entre les coefficients d'interaction rapportés dans cet article et les valeurs estimées ou publiées est satisfaisante dans la plupart des cas, étant donné la simplicité de l'appareil expérimental et les procédures expérimentales. On a observé une très bonne corrélation entre les coefficients d'interaction calculés par les auteurs et les valeurs de la littérature pour les mélanges R12/R152a, R134a/R134 et R22/R152a, mais une mauvaise corrélation pour le mélange R22-R142b. Les comparaisons entre les coefficients d'interaction publiés et évalués et entre les coefficients d'interaction rapportés et évalués laissent entendre que les techniques d'évaluation méritent d'être améliorées.

(Mots clés: Frigorigène; CFC; R12; R152a; R134a; R22; Mélange; Propriété chimique; Propriété physique)

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Additional emphasis on the acceptability of man-made chemicals in our global environment has resulted in controlled use and eventual elimination of some of the most useful chemical compounds ever employed in commerce and industry. Many of these compounds are used as working fluids in refrigeration or air-conditioning systems. Chlorine-containing refrigerants have been implicated in the stratospheric ozone depletion that occurs over the polar regions each spring and the build-up of infrared-absorbing atmospheric gases which contribute to the greenhouse warming of the earth. The applications for these refrigerants have become so essential to the structure of modern society that alternative, environmentally acceptable, substitutes must be found.

Unfortunately, the number of fluids which can function as refrigerants in conventionally designed vapour compression equipment is limited to a few chemical families of compounds which have the required stability and vapour pressure characteristics needed for refrigeration machines^{1,2}. For several of these essential applications it may become necessary to blend two or more known refrigerants to tailor a fluid with all the necessary thermophysical properties.

Essentially all of the combinations and permutations of hydrogen, fluorine and chlorine substitutions on methane and ethane carbon skeletons have been considered as potential refrigerants.¹ The result has been that no pure compound or known azeotrope will function as a 'drop-in' replacement for the chlorofluorocarbon (CFC) refrigerants being phased out by the Montreal Protocol³. Several authors have suggested that non-azeotropic (zeotropic) mixtures of refrigerants may be valuable in this regard^{4,5}. In addition to blending fluids to get the needed pressure-volume-temperature ($p-v-t$) behaviour, undesirable chemical or physical characteristics of one compound such as flammability or insolubility in oils can be mitigated through careful selection of the other components of the blend. For example, a ternary refrigerant mixture proposed as an R12 substitute compensates for the flammability of R152a by mixing it with appropriate amounts of R22 and R124.

To conveniently model the performance of refrigeration cycles, the thermodynamic properties of the refrigerant are required. Simple mixture models including an equation of state (EOS) and appropriate mixing rules have been developed. Several of these models have been coded into computer subroutines which can be conveniently used on a personal computer⁶⁻⁹.

A more thorough description of the two EOS used for comparison in this work is provided in references 7 and 8. Generally, the Carnahan-Starling-DeSantis (CSD) EOS is a two-parameter equation patterned after the van der Waals form with correlations for (a) intermolecular forces and (b) molecular volume. The six CSD EOS coefficients are obtained from second-order temperature fits of these correction factors. The Lee-Kesler-Plöcker (LKP) EOS uses a corresponding states approach derived from the Benedict-Webb-Rubin equation with generalized parameters. To add new compounds to the LKP set of refrigerant property subroutines, values for the critical temperature and pressure and the acentric factors must be known⁹. An essential parameter for accurately calculating the thermodynamic properties of mixtures with either the CSD or LKP routines is an interaction coefficient (IC) which characterizes and quantifies the

ideality or non-ideality of solutions formed by combination of two or more compounds. ICs are parameters used to generate better agreement between calculated refrigerant properties and experimental data.

Numerical values for an IC are determined by minimizing the sum of the squares of relative deviations between experimentally measured and calculated $p-v-t$ property data from known compositions. Adequate laboratory data are not available to calculate ICs for many of the refrigerant blends being considered as CFC alternatives in conventional and non-azeotropic refrigerant mixture applications. Some estimate of the IC is usually needed to model the performance of these blends in cycle simulations, and a rough estimate is preferable to an arbitrary guess or assuming ideal solution behaviour^{10,11}. Accordingly, the CSD and LKP refrigerant property routines contain methods for estimating ICs for mixed refrigerants based on measurable physical properties of the components.

Saturated vapour pressure measurements were made on the 18 binary refrigerant combinations listed in Table 1 as part of a research project to find substitutes for R12 with lower ozone depletion potential¹². These measurements were primarily taken to determine whether any constant boiling binary azeotropes were formed between the refrigerants being evaluated. The only azeotrope found for numerous tested binary, ternary or quaternary mixtures of R134a, R134, R152a, R142b, R23, R22 and R124 was a mixture of R134 and R142b with a mass fraction composition of 0.906 and 0.094, respectively. As an additional benefit, the data have been helpful in calculating ICs for a number of binary refrigerant combinations based on this saturated vapour pressure data and comparing these experimentally determined ICs with those estimated by computer algorithms in the CSD and LKP codes.

ICs for the CSD and LKP mixture models have been determined for the 18 refrigerant mixtures based on these experimental data. Nine of these were not previously reported for the CSD property routines; 15 of the 18 ICs reported for the LKP routines had not previously been reported. Comparisons between published, calculated and estimated ICs are given.

Experimental details

The test apparatus in which these measurements were made is shown schematically in Figure 1 and in the

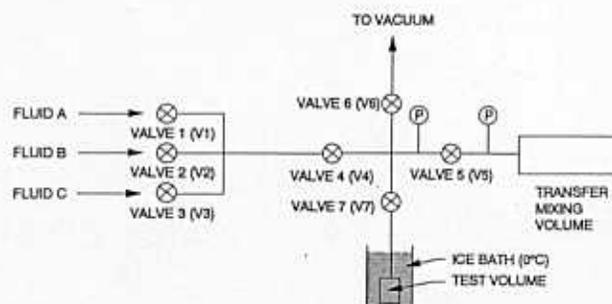


Figure 1 Schematic of apparatus used for vapour pressure measurements on known refrigerant mixtures. Valve and pressure transducer (P) arrangement

Figure 1 Schéma de l'appareil utilisé pour les mesures de la pression de vapeur de mélanges de frigorigènes connus. Agencement du transducteur de pression (P) et de la soupape

Table 1 Experimental saturated vapour pressure (bubble point) data for refrigerant mixtures at 0°C – data from reference 12

Tableau 1 Données expérimentales de la pression de vapeur saturée (point d'ébullition) pour des mélanges de frigorigènes à 0 deg C – données de la référence 12

Refrigerants	Corrected* liquid mole fractions	Corrected* liquid mass fractions	Measured vapour pressure (lbf in ⁻²)
R23/R22	0.089/0.911	0.073/0.927	93.57
R23/R134a	0.091/0.909	0.064/0.936	58.15
	0.480/0.520	0.388/0.612	137.56
R22/R134a	0.759/0.241	0.727/0.273	65.66
	0.497/0.503	0.455/0.545	59.58
	0.235/0.765	0.207/0.793	52.07
R22/R152a	0.757/0.243	0.803/0.197	59.83
	0.497/0.503	0.564/0.436	51.78
	0.243/0.757	0.296/0.704	44.75
R22/R134	0.762/0.238	0.731/0.269	66.44
	0.493/0.507	0.452/0.548	61.61
	0.236/0.764	0.208/0.792	49.70
R22/R124	0.755/0.245	0.661/0.339	58.39
	0.491/0.509	0.379/0.621	51.64
	0.237/0.763	0.164/0.836	40.41
R22/R142b	0.670/0.830	0.636/0.364	63.14
	0.492/0.508	0.454/0.546	55.89
	0.320/0.680	0.288/0.712	47.32
	0.142/0.858	0.125/0.875	29.60
R12/R152a	0.908/0.092	0.947/0.053	47.10
	0.811/0.189	0.887/0.113	50.21
	0.710/0.290	0.817/0.183	51.92
	0.501/0.499	0.648/0.352	52.20
	0.293/0.707	0.431/0.569	48.90
	0.141/0.859	0.231/0.769	44.93
R134a/R152a	0.758/0.242	0.829/0.171	41.42
	0.501/0.499	0.608/0.392	40.26
	0.243/0.757	0.331/0.669	39.49
	0.118/0.882	0.171/0.829	39.25
R134a/R134	0.906/0.094	0.906/0.094	41.99
	0.758/0.242	0.758/0.242	40.72
	0.500/0.500	0.500/0.500	38.30
	0.242/0.758	0.242/0.758	35.44
R134a/R124	0.906/0.094	0.878/0.122	41.54
	0.832/0.168	0.788/0.212	40.46
	0.758/0.242	0.701/0.299	39.04
	0.638/0.362	0.568/0.432	37.35
	0.497/0.503	0.425/0.575	34.77
	0.241/0.759	0.192/0.808	29.99
R134a/R142b	0.883/0.117	0.884/0.116	41.29
	0.757/0.243	0.760/0.240	38.90
	0.592/0.408	0.596/0.404	36.50
	0.497/0.503	0.500/0.500	34.61
	0.366/0.634	0.369/0.631	31.93
	0.238/0.762	0.241/0.759	30.14
R152a/R134	0.741/0.259	0.650/0.350	36.98
	0.499/0.501	0.392/0.608	35.18
	0.240/0.760	0.170/0.830	33.55
	0.756/0.244	0.600/0.400	35.05
	0.581/0.419	0.401/0.599	32.49
	0.237/0.763	0.131/0.869	27.85
R152a/R142b	0.755/0.245	0.669/0.331	35.21
	0.496/0.504	0.392/0.608	31.00
	0.240/0.760	0.172/0.828	26.64
R134/R124	0.906/0.094	0.878/0.122	32.67
	0.808/0.192	0.758/0.242	32.75
	0.706/0.294	0.642/0.358	32.36
	0.602/0.398	0.530/0.470	31.83
	0.446/0.554	0.375/0.625	30.10
	0.290/0.710	0.234/0.766	28.57
	0.142/0.858	0.110/0.890	26.52
	0.943/0.057	0.944/0.056	32.39
R134/R142b	0.905/0.095	0.906/0.094	32.45
	0.856/0.144	0.858/0.142	32.11

Table 1 (continued)

Refrigerants	Corrected* liquid mole fractions	Corrected* liquid mass fractions	Measured vapour pressure (lbf in ⁻²)
	0.756/0.244	0.759/0.241	31.62
	0.498/0.502	0.501/0.499	29.63
	0.254/0.746	0.257/0.743	26.17
R124/R142b	0.757/0.243	0.809/0.191	23.37
	0.512/0.488	0.587/0.413	22.95
	0.244/0.756	0.305/0.695	22.07

*Mole and mass fractions corrected for gas compressibilities. Internal volume of the mixing and test volumes plus interconnecting tubing was 0.174 l

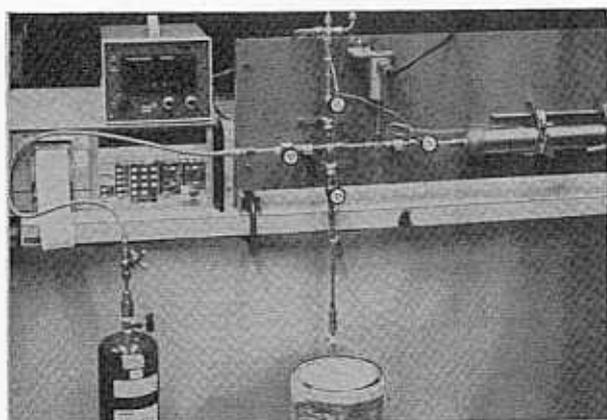


Figure 2 Photograph of apparatus used to prepare refrigerant mixtures of known concentration and measure saturated vapour concentrations.

Figure 2 Photographie d'un appareil utilisé pour préparer des mélanges de frigorigènes de concentration connues et pour mesurer des concentrations de vapeur saturées

Figure 2 photograph. The transfer mixing volume has an internal capacity of approximately 150 ml compared with 10 ml for the test volume. These chambers are interconnected with tubing which has a diameter of only 0.5 cm. The pressure transducers have a rated accuracy of ± 3.4 kPa (0.5 lbf in⁻²).

The entire apparatus was evacuated to below 13 pa (0.1 mmHg) prior to each mixing and test condition. The fluids to be mixed were attached to the left side of the apparatus and transferred to the 'transfer mixing volume' where they were mixed at room temperature. System pressures were measured after the addition of each component so that mixture compositions could be calculated from the partial pressures after compressibility corrections. After the required additions, an ideal gas mixture was assumed in this transfer vessel.

Fluids with the highest boiling point were transferred first in order to ensure the highest possible mixed gas pressure and thus the largest quantity of fluid in the transfer mixing volume. Prior to the addition of each component, valve V5 was closed and all lines were evacuated.

A period of several minutes was allowed to ensure reasonably good mixing of the fluids within the short mixing distances of the transfer mixing volume. No mechanical or thermal aids were used to facilitate mixing. Valves V5 and V7 were then opened to allow the mixed fluid to pass to the test volume. When the test volume

was immersed in a stirred ice bath, a near equilibrium pressure was obtained very quickly (about 10 s). After about another minute, a temperature measurement of 0.0 °C (32 °F) was obtained, and the saturated vapour pressure was recorded. Due to the quick cool-down response, the liquid condensed in the test volume is very nearly the same composition as the gas in the transfer mixing volume.

The diameter of the tube in the vapour space above the liquid is only 0.5 cm, and its length to the large mixing chamber is about 60 cm. Thus, there is insufficient time for gaseous diffusion to establish equilibrium between the large gaseous mixing chamber and the distant small liquid condensing vessel. Had this occurred, the less volatile components would have been preferentially condensed. The condensing test volume and transfer mixing volume were, however, deliberately placed far apart with a large diffusion impedance in order to preclude the preferential distillation problem. This inference was confirmed by the observation that saturated pressure measurements remained stable for several minutes after the initial reading was taken.

The molar and mass fractions of each component in the liquid phase at 0 °C were calculated using the CSD refrigerant property routines and the partial pressures of components at room temperature, the internal volume of the test manifold, and the temperatures at which the measurements were taken. These calculations made it possible to compensate for the compressibility of each gas.

From component specifications and the techniques used to make these evaluations, the accuracy of the vapour pressure measurements is estimated to be ± 3.4 kPa (0.5 lbf in⁻²). The primary unknown variable in the fluid compositions is the relative purity of the fluids themselves, which have been measured as 99% pure by vendor tests.

According to a parameter sensitivity analysis performed by the Centre de Recherche Industrielle du Québec, the CSD IC appears to be most sensitive to inaccuracies in the experimental pressure measurements.¹³

Results

ICs which best fit the experimental data in Table 1 were determined for both the CSD and LKP EOS refrigerant property routines by comparing the experimentally measured saturated vapour pressure with the value calculated from the appropriate computer subroutines. Experimental liquid concentrations calculated from the

partial pressures and corrected for individual compressibilities, temperatures and a trial IC value were used as inputs for these subroutines. The best IC value was that which minimized the sum of the squared differences between calculated and experimental pressures (best least squares fit) for all of the data points.

IC values for the CSD system of equations, $f_{1,2}$ s, were calculated to three decimal places. Additional significant digits had very little effect on calculated pressures.

The κ_{ij} values calculated from the LKP routines were also computed out to three decimal places, which implies a minimum of three significant figures. The LKP routines are more sensitive to smaller absolute changes in the value of ICs. Since the total range for LKP κ_{ij} values is from 0.944 to 1.060, more significant figures are needed to show variations between refrigerant pairs.

Table 2 contains the ICs calculated using the CSD routines and the concentration/temperature/vapour pressure data in Table 1. Column 2 in Table 2 contains the ranges of ICs which were needed to fit all of the mixed refrigerant data points from Table 1. The nine ICs which are contained in the most current and earlier versions of the REFPROP® refrigerants database from the National Institute of Standards and Technology (NIST) are also tabulated along with ICs estimated in a paper by Morrison and McLinden¹¹.

Mixtures of R12 and R152a which, when blended in the appropriate ratios, form the R500 azeotrope, were used as control samples to demonstrate that refrigerant mixtures would exhibit a maximum or minimum in plots of saturated vapour pressure versus mixture composition. These mixtures also served as good controls to verify the validity of this analysis.

Results for the experimentally measured and known LKP ICs, κ_{ij} s, are presented in Table 3. As mentioned earlier, the LKP refrigerant property subroutines contain an algorithm based on critical temperatures and critical molar volumes of the mixed constituents to predict the LKP IC, Equation (1). 'Estimated' κ_{ij} s calculated by this algorithm are also listed in this table. Values for the 'published' κ_{ij} s were taken directly from the source code for the LKP routines provided by the Institute for Refrigeration and Heat Pumps at the Technical University in Hanover.

$$\kappa_{ij} = A + B \left(\frac{T_{cr(j)} \times V_{cr(j)}}{T_{cr(i)} \times V_{cr(i)}} \right) + C \left(\frac{T_{cr(j)} \times V_{cr(j)}}{T_{cr(i)} \times V_{cr(i)}} \right)^2 \quad (1)$$

where: κ_{ij} = the LKP interaction coefficient for a mixture of refrigerant i and j

$$A = 0.97593011$$

$$B = 1.30196 \times 10^{-2}$$

$$C = 8.60429 \times 10^{-3}$$

T_{cr} = Critical temperature (K)

V_{cr} = Critical volume (molar)

(j) = j th component

(i) = i th component

Discussion

These experimentally determined ICs are presented here to help researchers who must use these values to model the performance of mixtures in cycle simulations and to provide comparisons between experimentally measured IC values and those estimated using mathematical

algorithms. Obviously, more accurate transducers and more precise laboratory procedures would have been used if the primary goal for the vapour pressure measurements in Table 1 was to calculate binary ICs. Reasonably precise estimates are given in Tables 2 and 3 for many refrigerant combinations that are of interest as mixtures which could be used as CFC or hydrochlorofluorocarbon alternatives.

One potential shortcoming with the data used for the analysis is that it was all obtained at 0 °C (32 °F). Values of interaction coefficients may or may not be weak functions of temperature, so vapour pressure measurements for known concentrations over a range of temperatures would be preferable for these calculations. Morrison and McLinden have shown that ICs are also functions of concentration, although this feature is not usually implemented in these simpler equations of state.¹⁴

Comparisons of experimental to published ICs in Table 2 show excellent agreement for the R12/R152a, R134a/R134 and R22/R152a combinations. Reasonably good agreement is seen in the values for R22/R124, R134a/R152a and R152a/R134, especially since these values are so close to zero.

One of the largest discrepancies between an experimental and established IC in the CSD data is for the R22/R142b combination. A relatively large difference is also seen for this pair in the LKP data from Table 3. This blend has frequently been suggested as an alternative for R12, and a substantial amount of laboratory work has been carried out with R22/R142b blends^{15,16}. The established value given in the CSD code was calculated from data presented in 1986 by A. Valts *et al.*¹⁷.

A wide range of IC values was needed to fit each experimental data point for the various concentrations in Tables 2 and 3. Variations of IC values with concentration are not accounted for in either the CSD or LKP refrigerant property routines. An atypically large range is seen for the R22/R142b combination in Table 2.

Some rather large deviations are seen between published and estimated ICs in Tables 2 and 3. Most noticeable are those for the R23/R22, R134a/R134 and R152a/R134 pairs in Table 2 and the R12/R152a pair in Table 3. Additional experimental data like those presented in this paper may be useful in refining algorithms used to estimate IC values.

Only one or two experimental data points were available to calculate ICs for the blends containing R23, so these values may be questionable. The limiting pressure for the transducer used to obtain the experimental data was 1400 kPa (200 lbf in⁻²) which further limits the usefulness of these results.

LKP κ_{ij} s calculated from the data in Table 1 are given in Table 3. Again, these are compared to those calculated from the previously described algorithm (Equation (1)) and three established values from the LKP computer code as it was received from the University of Hanover. Very large deviations are seen between the experimental and calculated values for the R22/R134 combination which gave a fairly tight range of experimental results for three different concentrations. Many of the ICs calculated by the LKP algorithm are outside the range of experimental ICs which fit the experimental data.

It is also bothersome that the calculated and published LKP ICs for the R12/R152a combination differ by such a large amount from the estimated value in Table 3, despite all of the literature data for the R500

Table 2 CSD interaction coefficients calculated from experimental data; comparison with published values
Tableau 2 Coefficients d'interaction de CSD calculés avec les données expérimentales – comparaison avec les valeurs publiées

Refrigerant pair	Range of interaction coefficients which fit data	Best least square fit interaction coefficient	Published ^P or estimated ^E interaction coefficient ^d
R-23/R-22		-0.041 ^b	0.032 ^P 0.000 ^E
R23/R134a	-1.00-(-0.066)	-0.087 ^c	-0.010 ^E
R22/R134a	0.010-0.016	0.015	0.0078 ^P -0.002 ^E
R22/R152a	-0.036-(-0.012)	-0.019	-0.014 ^P 0.002 ^E
R22/R134	0.044-0.056	0.052	0.008 ^E
R22/R124	0.013-0.029	0.019	0.009 ^P 0.002 ^E
R22/R142b	0.016-0.064	0.044	-0.007 ^P -0.007 ^E
R12/R152a (R500 azeotrope)	0.059-0.076	0.063	0.066 ^P 0.080 ^E
R134a/R152a	-0.005-0.016	0.008	-0.007 ^P -0.007 ^E
R134a/R134	0.006-0.014	0.007	0.007 ^P 0.020 ^E
R134a/R124	0.015-0.029	0.019	0.010 ^E
R134a/R142b	0.027-0.039	0.031	-0.005 ^E
R152a/R134	-0.005-0.003	-0.002	0.006 ^P 0.030 ^E
R152a/R124	-0.003-0.004	-0.001	0.020 ^E
R152a/R142b	0.011-0.015	0.013	0.000 ^E
R134/R124	0.021-0.030	0.025	0.002 ^E
R134/R142b	0.025-0.035	0.030	0.008 ^E
R124/R142b	0.004-0.008	0.006	0.006 ^E

^aPublished interaction coefficients are from the National Institute of Standards and Technology (NIST) REFPROP database, Versions 2.0 and 3.0.
^bEstimated interaction coefficients are taken from reference 11.

^cOnly one data point

^dOnly two data points

Table 3 LKP interaction coefficients calculated from experimental data; comparison with calculated and published values
Tableau 3 Coefficients d'interaction de LKP calculés avec les données expérimentales – comparaison avec les valeurs calculées et établies

Refrigerant pair	Range of interaction coefficients which fit data	Best least square fit interaction coefficient	Published ^P or estimated ^E interaction coefficient ^d
R23/R22	—	1.029 ^b	0.997 ^E
R23/R134a	1.050-1.060	1.055 ^c	1.007 ^E
R22/R134a	0.991-0.994	0.993	0.990 ^E
R22/R152a	1.011-1.027	1.015	0.990 ^E 1.0052 ^P
R22/R134	0.956-0.965	0.958	1.000 ^E
R22/R124	0.975-1.004	0.980	0.998 ^E
R22/R142b	0.953-0.963	0.960	0.994 ^E 0.998 64 ^P
R12/R152a (R500 azeotrope)	0.944-0.954	0.951	0.984 ^E 0.942 745 ^P
R134a/R152a	0.991-1.007	1.003	0.986 ^E
R134a/R134	0.992-1.007	0.993	0.992 ^E
R134a/R124	0.980-0.995	0.985	0.991 ^E
R134a/R142b	0.976-0.991	0.983	0.989 ^E
R152a/R134	0.997-0.999	0.998	0.992 ^E
R152a/R124	0.985-0.993	0.989	0.991 ^E
R152a/R142b	0.991-0.992	0.991	0.989 ^E
R134/R124	0.956-0.970	0.966	0.985 ^E
R134/R142b	0.946-0.983	0.974	0.984 ^E
R124/R142b	0.981-0.994	0.987	0.984 ^E

^aUniversity of Hanover, Institute for Refrigeration and Heat Pumps, Hanover, Germany.

^bOnly one data point

^cOnly two data points

azeotrope. The correlation between ICs and the respective critical temperatures and volumes (Equation (1)) was originally developed for hydrocarbon/hydrocarbon or hydrocarbon/aromatic systems¹⁰. It should be refined for halogenated hydrocarbon/halogenated hydrocarbon systems more indicative of mixed refrigerants. Established values given in the LKP code and the values presented in this paper may furnish a good starting point.

Despite its variability, the use of a computer algorithm to estimate ICs from component parameters is a very convenient feature of the CSD and LKP routines, and it provides a more valid estimate for this value than assuming ideal solution behaviour, i.e. $f_{12} = 0.000$ or $\kappa_{ij} = 1.000$.

Conclusions and recommendations

Estimates of binary interaction coefficients for several potentially useful refrigerant mixtures are provided for both the CSD and LKP refrigerant property computer subroutines. Many of these have not been previously reported in the open literature.

Comparisons between the IC estimates given in this paper and those previously reported show remarkable agreement for combinations such as R12/R152a, R134a/R134 and R22/R152a but relatively poor agreement with the well-known and characterized R22/R142b blend. Further experimental verification is suggested.

Comparisons between experimental ICs and those calculated from physical properties or critical constants of components suggest that a refinement of the computerized estimation algorithm would be desirable.

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